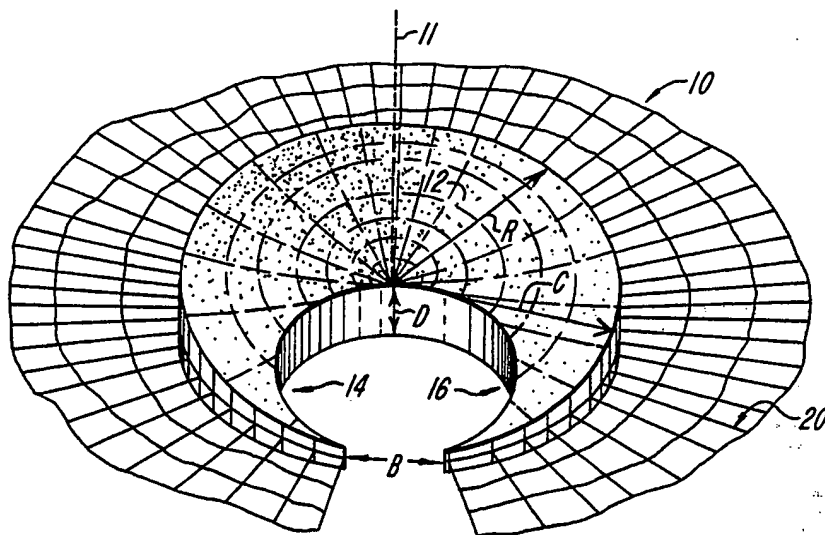




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>5</sup> :</b> A61F 2/28, 2/30, 2/38 A61F 2/54	<b>A1</b>	<b>(11) International Publication Number:</b> WO 90/09769 <b>(43) International Publication Date:</b> 7 September 1990 (07.09.90)
<b>(21) International Application Number:</b> PCT/US90/01141 <b>(22) International Filing Date:</b> 1 March 1990 (01.03.90) <b>(30) Priority data:</b> 317,951                      2 March 1989 (02.03.89)                      US <b>(71) Applicant:</b> REGEN CORPORATION [US/US]; 3727 Buchanan Street, San Francisco, CA 94123 (US). <b>(72) Inventor:</b> STONE, Kevin, R. ; 133 Retiro Way, San Francisco, CA 94123 (US). <b>(74) Agents:</b> LAPPIN, Mark, G. et al.; Lahive & Cockfield, 60 State Street, Boston, MA 02109 (US).		<b>(81) Designated States:</b> AT (European patent), AU, BE (European patent), CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent).  <b>Published</b> <i>With international search report.          Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

**(54) Title:** PROSTHETIC MENISCUS**(57) Abstract**

A prosthetic, resorbable meniscus (10) and method of its fabrication are disclosed. The prosthetic meniscus (10) can be implanted in a human knee where it can act as a scaffold for regrowth of native meniscal tissues. The meniscus (10) comprises a dry, porous, matrix of biocompatible and bioresorbable fibers, at least a portion of which may be crosslinked. The fibers include natural polymers or analogs or mixtures thereof. The matrix is adapted to have *in vivo* an outer surface contour substantially the same as that of a natural meniscus. The matrix has pore size in the approximate range of greater than 50 microns to less than about 500 microns. With this configuration, the matrix establishes an at least partially bioresorbable scaffold adapted for ingrowth of meniscal fibrochondrocytes.

***FOR THE PURPOSES OF INFORMATION ONLY***

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MG	Madagascar
AU	Australia	FI	Finland	ML	Mali
BB	Barbados	FR	France	MR	Mauritania
BE	Belgium	GA	Gabon	MW	Malawi
BF	Burkina Faso	GB	United Kingdom	NL	Netherlands
BG	Bulgaria	HU	Hungary	NO	Norway
BJ	Benin	IT	Italy	RO	Romania
BR	Brazil	JP	Japan	SD	Sudan
CA	Canada	KP	Democratic People's Republic of Korea	SE	Sweden
CF	Central African Republic	KR	Republic of Korea	SN	Senegal
CG	Congo	LJ	Liechtenstein	SU	Soviet Union
CH	Switzerland	LK	Sri Lanka	TD	Chad
CM	Cameroon	LU	Luxembourg	TG	Togo
DE	Germany, Federal Republic of	MC	Monaco	US	United States of America
DK	Denmark				

5

PROSTHETIC MENISCUSField of the Invention

The present invention is in the field of  
10 implantable medical devices, and more particularly,  
is directed to devices useful as prosthetic menisci,  
and in vivo scaffolds for regeneration of meniscal  
tissue and to methods for their fabrication.

15 Background of the Disclosure

The medial and lateral menisci are a pair of  
cartilaginous structures in the knee joint which  
together act as a crucial stabilizer, a mechanism for  
20 force distribution, and a lubricant in the area of  
contact between the tibia and femur. Without the  
menisci, stress concentration occurs in the knee in  
conjunction with abnormal joint mechanics, and  
premature development of arthritic changes occurs.

25

In the prior art, treatment of injured or  
diseased menisci has generally been both by surgical  
repair and by excision. With excision, regeneration  
of meniscal tissue may occur. Additionally, it is  
30 known that meniscal fibrochondrocytes have the  
ability to migrate into a defect filled with a fibrin  
clot and form tissue apparently similar to normal  
meniscal fibrocartilage. When an adequate matrix  
scaffold is present within a meniscal defect, such

-2-

meniscal fibrocartilage may be formed. Meniscal tissue is also capable of self-repair when exposed to bleeding tissues, and additionally, it is also known in the prior art that meniscal cells in tissue culture are capable of cell division and matrix synthesis. Replacement of an injured meniscus in an otherwise healthy joint may prevent arthritic changes and may stabilize the joint. In diseased joints, replacement of the meniscus may reduce the progression of the disease process, and may provide pain relief. Allografting or meniscal transplantation, is one method of replacement which has been executed both in dogs and in humans. However, this approach has been only partially successful over the long term due to the host's immunologic response to the graft, to failures in the cryopreservation process, and to failures of the attachment sites.

20 In alternative prior art replacement approaches, menisci have been replaced with prostheses composed of permanent artificial materials. Such prosthesis have been constructed of purely artificial materials in order to minimize the possibility of an immunological response. In addition, the use of such materials is believed to be advantageous because it permits construction of a structure which can withstand the high and repeated loads which are encountered in the knee joint, and because it can alter the joint mechanics in beneficial ways that biological materials would not tolerate.

-3-

For example, a Teflon net has been used to replace the resected meniscus of a dog upon which fibrous ingrowth or regeneration was observed, although accompanied by significant chondral abrasion. A prosthetic meniscus has also been constructed from resilient materials such as silicone rubber or Teflon with reinforcing materials of stainless steel or nylon strands (U.S. Patent No. 4,502,161). A meniscal component has also been made from resilient plastic materials (U.S. Patent No. 4,085,466). In addition, reconstruction of meniscal lesions has been attempted with carbon-fiber-polyurethane-poly (L-lactide), but its success with these materials is minimal (Leeslag et al.,

15 Biological and Biomechanical Performance of Biomaterials (Christel et al., eds.) Elsevier Science Publishers B.V., Amsterdam. 1986, pp: 347-352).

However, the replacement of meniscal tissue with structures consisting of permanent artificial materials generally has been unsuccessful, principally because the opposing articular cartilage of human and animal joints is fragile. The articular cartilage in the knee will not withstand abrasive interfaces, nor compliance variances from normal, which eventually results from the implantation of prior art artificial menisci. Additionally, joint forces are multiples of body weight which, in the case of the knee and hip, are typically encountered over a million cycles per year. Thus far, prior art permanent artificial menisci have not been composed of materials having natural meniscal properties, nor

-4-

have they been able to be positioned securely enough to withstand such routine forces.

Therefore, what is needed is an improved  
5 prosthetic meniscus composed of biocompatible materials which are soft and lubricating.

Repair of other tissues such as skin and nerve has been attempted using both synthetic and  
10 natural materials. For example, Yannas et al., fashioned endodermal implants, and artificial epidermis out of natural collagen and glycosaminoglycans (U.S. Patent No. 4,060,081).  
Nyiles et al. (Trans. Am. Soc. Artif. Intern. Organs  
15 (1983) 29:307-312) reported the use of synthetic resorbable polyesters for peripheral nerve regeneration applications, and the use of collagen conduits as a scaffold for nerve regeneration.

20 However, even with the foregoing technologies which have been applied to the reconstruction of anatomical structures other than knee joints, a structure suitable as a prosthetic meniscus and constructed from totally resorbable  
25 natural materials, or analogs thereof, has not been developed in the prior art.

Accordingly, it is an object of this invention to provide an improved meniscal prosthesis  
30 which allows for normal joint motion.

Another object is to provide a meniscal replacement or prosthesis which is biomechanically

-5-

able to withstand normal joint forces and is able to function at those loads to protect the cartilage and stabilize the joint.

5            Yet another object is to provide a resorbable meniscal prosthesis which acts as a temporary in vivo scaffold for meniscal fibrocartilage infiltration and regeneration.

10           Still another object is to provide a meniscal prosthesis which is composed of biocompatible materials having an organization equivalent to that of the normal meniscus.

15           A further object is to provide a meniscal prosthesis which is adapted for implantation by standard operative techniques.

            Another object is to provide a method of  
20 regenerating meniscal tissue in vivo.

            Still a further object is to provide a method by which such prosthetic menisci can be fabricated.

25

Summary of the Invention

The present invention provides a biocompatible and bioresorbable structure for  
5 implantation into the knee joint which assumes the form and role of a meniscus. This prosthetic meniscus promotes and provides a scaffold for the regeneration of tissue having the physical characteristics of a natural meniscus.

10

The prosthetic meniscus of the present invention is generally a dry, porous matrix of biocompatible bioresorbable fibers, including natural polymers or analogs or mixtures thereof. The matrix  
15 is adapted to have in vivo an outer surface contour substantially the same as that of a natural meniscus. Further, the matrix has pore size in the approximate range of greater than 50 microns to less than about 500 microns. With this configuration, the  
20 matrix establishes an at least partially bioresorbable scaffold adapted for ingrowth of meniscal fibrochondrocytes. The matrix may have the shape of a circumferentially extending wedge spanning a predetermined angle greater than 0 degrees, and  
25 less than or equal to 360 degrees, and having a thickness in its central region which is less than its thickness in its peripheral regions. In some forms of the invention, the matrix may assume the shape of a simple wedge, a crescent-shaped wedge with  
30 a wide central region between two narrow distal tip regions, or a circumferentially extending wedge spanning an angle of 360 degrees and having a depressed (concave) central region, for example.



-7-

The matrix is composed of biocompatible and bioresorbable fibers, a portion of which may be crosslinked. The fibers include a natural material or an analog of a natural material such as a  
5 biosynthetic analog. In a preferred embodiment of the invention, the fibers of the matrix are polymers of, for example, natural molecules such as those obtained from animal or human tissue. Natural fibers useful for the same purpose include collagen,  
10 elastin, reticulin, analogs thereof, and mixtures thereof.

In some forms of the invention, the fibers may be randomly orientated throughout the matrix, or  
15 may be ordered at specified regions. Alternatively, the fibers may assume substantially circumferentially extending or substantially radially extending orientations throughout the prosthetic meniscus.

20 The matrix may also include glycosaminoglycan molecules (GAGs) interspersed with the fibers. GAGs are any mucopolysaccharide molecules which provide lubrication and crosslinks for the prosthetic meniscus of the invention. In the  
25 preferred aspects of the invention, GAGs such as chondroitin 4-sulfate, chondroitin 6-sulfate, keratan sulfate, dermatan sulfate, heparin sulfate, hyaluronic acid, and mixtures thereof are a component of the matrix. These GAGs may be uniformly dispersed  
30 throughout the prosthetic meniscus as individual molecules, or may be present in varying amounts in different regions of the structure.

In various forms of the invention, GAGs may directly participate in covalent crosslinking formation with the fibers, or may interact with the fibers mechanically in the form of entanglement or  
5 through interlocking mechanisms, forming stable fiber-GAG complexes.

The matrix include about 75-100% natural and/or synthetic fibers and about 0-25% GAGs by dry  
10 weight, the proportions of which may be constant throughout the structure or may be variable.

In a preferred embodiment of the invention, the matrix has a density of about 0.07 to 0.50  
15 g matrix/cm<sup>3</sup> where "g matrix/cm<sup>3</sup>" is a unit connoting the number of grams in a cubic centimeter of the matrix. In addition, it has an interfibrillary and interfibrillary space of about 2 to 25 cm<sup>3</sup>/g matrix.

20 In another form of the invention, the prosthetic meniscus may further comprise a mesh composed of a bioresorbable, biocompatible material which is attached to portions of the outer surface of the matrix. The mesh aids in the successful  
25 implantation of the prosthetic meniscus into the knee joint by providing a temporary anchoring mechanism.

The invention also includes a method of regenerating meniscal tissue in vivo. This method  
30 includes fabricating a prosthetic meniscus and implanting it into the knee joint by surgical procedures.

Further, the invention includes a method for fabricating a prosthetic meniscus of the type described above. Generally, the method includes placing a plurality of fibers and/or fibers and GAGs  
5 into a mold having a shape useful for knee joint function, subjecting the fibers (and GAGs) in the mold to two cycles of freezing and thawing, contacting said fibers or said fibers and GAGs with a chemical crosslinking reagent such that the fibers  
10 then assume the shape of the mold, and lyophilizing the resulting structure to obtain a dry, porous, volume matrix.

The fibers may be laid down in a  
15 circumferential orientation by rotating the mold as they are placed therein. Alternatively the fibers in the mold may be compressed with a rotating piston. Radial orientation of the fibers is produced by manually painting the fibers in a linear, radially  
20 directed fashion.

Specific densities and pore sizes may be obtained in various regions of the matrix by compressing the fibers or fibers and GAGs in the mold  
25 prior to the second freeze-thaw cycle, subsequent to the chemical crosslinking step. This may be accomplished by applying pressure to a specific region of the matrix with a piston of a predetermined shape.

30

In a preferred aspect of the invention, the crosslinking step is performed using chemical agents which form intramolecular and intermolecular



-10-

crosslinks. Useful chemical agents include, for example, glutaraldehyde, formaldehyde, biocompatible bifunctional aldehydes, carbodiimides, hexamethylene diisocyanate, bis-ionidates, glyoxal, polyglycerol  
5 polyglycidyl ether, glyoxal, and mixtures thereof. Particularly useful crosslinking agents are 1-ethyl, 3-(3-dimethylaminopropyl), polyglycerol polyglycidyl ether, and glutaraldehyde.

10 In other aspects of the invention, an additional crosslinking step is performed by lyophilizing the chemically crosslinked matrix and then subjecting it to dehydrothermal crosslinking procedures.

15

The invention will next be described in connection with certain illustrated embodiments. However, it should be clear that various modifications, additions, and deletions can be made  
20 without departing from the spirit or scope of the invention.

-11-

Brief Description of the Drawings

The foregoing and other objects of this invention, the various features thereof, as well as 5 the invention, itself, may be more fully understood from the following description, when read together with the accompanying drawings.

FIG. 1 shows a simplified diagrammatic 10 representation of a human knee joint, with menisci in native positioning;

FIG. 1A is a diagrammatic representation of a cut-away view of the knee joint showing the medial 15 and lateral menisci as they are positioned in vivo over the medial and lateral condyles.

FIG. 2 shows a perspective view of an exemplary prosthetic meniscus in accordance with the 20 present invention;

FIG. 3 shows a perspective radial section of the prosthetic meniscus of FIG. 2;

25 FIG. 4 shows a perspective view of an alternative embodiment of the present invention;

FIG. 5 shows a sectional view along line 5-5 of the prosthetic meniscus of FIG. 4.

30

FIG. 6 shows a mold designed for the fabrication of a prosthetic meniscus having a cylindrical pad shape.

FIG. 7 shows a mold designed for the fabrication of a prosthetic meniscus having a crescent-shaped wedge form.

FIG. 8 shows a mold designed for the  
5 fabrication of a cylindrical prosthetic meniscus.

FIG. 9 is a photographic representation of in vivo meniscal regrowth after 80% resection and implantation of the prosthetic meniscus.

FIG. 10 is a photographic representation of  
10 an explanted canine meniscus containing a section of scaffold, and demonstrating in vitro regrowth of meniscal tissues into the scaffold.

FIG. 11 is a photographic representation of  
15 two canine knee joints three months after surgical resection.

FIG. 12 is a series of graphs showing the hydrodynamic profiles of the proteoglycan aggregates in the regenerated meniscus (FIG. 12B) compared to the resected rim alone (FIG. 12D), and compared with  
20 control samples including the remaining fibrocartilage post-resection in the medium (FIG. 12A) and the remaining fibrocartilage post-resection in the associative extract (FIG. 12C).

**SUBSTITUTE SHEET**

### Description of the Invention

It has been discovered that a prosthetic meniscus fabricated from biocompatible and bioresorbable fibers can be surgically implanted into the knee joint so as to provide normal joint motion and strength. This prosthetic meniscus also acts as a scaffold for regenerating meniscal tissue whose ingrowth is encouraged by the physical characteristics of the implanted device.

FIG. 1 shows a diagrammatic representation of the normal positioning of medial meniscus 7 and lateral meniscus 8 in the human knee joint 3 between the femur 2 and tibia 4. These menisci, when compressed between the femur 2 and tibia 4, become tough except at their points of attachment. FIG. 1A shows the in vivo structure of medial meniscus 7 and lateral meniscus 8 in the knee joint 3. The menisci conform to the shapes of the surfaces between which they are positioned, thereby resulting in two distinct in vivo forms. For example, the medial meniscus 7 has a relatively open crescent shape, while the lateral meniscus 8 has a relatively closed crescent shape.

An exemplary prosthetic meniscus 10 is shown in FIG. 2. The prosthetic meniscus 10 is a generally wedge-shaped, porous dry matrix or scaffold which extends circumferentially or laterally at least in part about a central axis 11. In the preferred form, the prosthetic meniscus 10 has the shape of a crescent-shaped wedge, extending circumferentially



about the axis 11, and comprising a relatively wide central region 12 between two narrow distal regions 14 and 16. In the preferred form, the wedge has maximum height A at its peripheral edge of  
5 approximately 0.4 inches, a height D at its central point of approximately 0.2 inches, and a maximum radial dimension C of approximately 1.0 inches. The crescent shaped wedge subtends an angle B about axis 11 substantially in the range of about 135 to about  
10 155 degrees, and preferably of about 150 degrees.

In the embodiment illustrated in Fig. 2, the prosthetic meniscus 10 includes a mesh member 20 extending from its peripheral edge. The mesh member 20 is composed of a biocompatible, bioresorbable  
15 material, and provides a readily used means for anchoring the array 10 in place. The mesh member 20 may function in this capacity until sufficient tissue ingrowth occurs to then provide that function. By way of an example, the mesh member 20 may be a #1  
20 mesh screen composed of absorbable suture materials such as polyglyconate, Dexon, or polydioxane (PDS) woven into a mesh. Non-absorbable suture materials such as Goretex may also be used.

FIGS. 4 and 5 show an additional embodiment  
25 of the present invention which is similar in composition to the prosthetic meniscus depicted in FIG. 2. More particularly, FIG. 4 depicts a right circular cylinder-shaped meniscus 22, extending fully about axis 11, i.e. where angle B equals 0 degrees.  
30 (i.e. the meniscus subtends 360 degrees.) FIG. 5 shows a sectional view along line 5-5 of the meniscus

**SUBSTITUTE SHEET**

-15-

shown in FIG. 4. The device illustrated in Figs. 4 and 5 show the shape of the meniscus 22 when implanted; that is, the height D at areas 11 is less than the peripheral height A of the device. Prior to 5 implantation, the device 22 may in some cases not have this relationship but upon implantation, the normal loads applied by the body force this conformation.

10 In alternative forms of the invention, still other shapes may be used. For example, it is not required that the wedge be symmetrical. These 15 embodiments may have densities of collagen fibers and dispersions of GAG molecules and crosslinks, permitting accommodation of differing stress levels, rates of ingrowth, and resiliency. Differing 20 densities may be obtained in vivo where a device having uniform density is implanted, and body loading causes non-uniform compression of the device.

25 The prosthetic meniscus may be fabricated of any biocompatible, bioresorbable fibers which include a natural material or an analog thereof; preferably polymeric in structure, which can provide mechanical 30 strength and protection and lubrication while encouraging tissue ingrowth (e.g., collagen, reticulin, elastin, cellulose, or biosynthetic analogs thereof). These fibers may be ordered in substantially circumferentially-extending or 35 substantially radially-extending orientations, with the density of fibers being substantially uniform throughout the matrix. Alternatively, the matrix fibers may be unordered. In either the ordered or

-16-

unordered configuration, the density of the fibers may be non-uniform. In the non-uniform configuration, relatively high densities of fibers may be established at anticipated points of high stress  
5 by local application.

In an alternative aspect of the invention, the intrafibrillary and interfibrillary space is relatively high, a condition which promotes ingrowth  
10 of regenerated meniscal tissue. For example, the density of the meniscus may be in the range of about 10-25 g matrix/cm<sup>3</sup>. Alternatively, the intrafibrillary and interfibrillary space is relatively low, a condition which provides  
15 cushioning, lubrication, and mechanical support for the knee joint and which retards tissue and cell ingrowth, thereby diminishing the rate of scaffold resorption (e.g., density is in the range of about 2-10 g matrix/cm<sup>3</sup>).

20

The temporary stability of the shape of the structure when in vivo, and the rate of meniscal resorption, are both attributed to the effective crosslinking formation between at least one portion  
25 of the fibers. The crosslinking reagents used may be any biocompatible bifunctional reagents which interacts with amino groups, carboxyl, or hydroxyl groups on a single fiber (intramolecular crosslinks), or the fibers or on the fibers and the GAGs,  
30 resulting in covalent bond formation between adjacent molecules (intermolecular crosslinks). Useful crosslinking reagents include aldehydes, hexamethylene

-17-

diisocyanate, bis-imidates, polyglycerol polyglycidyl ether, and carbodiimides.

The crosslinked device maintains sufficient  
5 degree of hydrophilicity and elasticity which  
simulates the properties of the natural meniscus,  
i.e., ability to sustain mechanical stress and to  
protect and lubricate articular surfaces. In  
addition, the structure provides an ideal environment  
10 for cell infiltration and extracellular matrix  
synthesis and deposition resulting in regeneration of  
natural meniscal tissue.

GAGs may be dispersed throughout the  
15 fibers. Alternatively, they may act as  
intermolecular crosslinks between fibers. These GAG  
crosslinks are composed typically of at least one of  
the group of molecules consisting of chondroitin  
4-sulfate, chondroitin 6-sulfate, keratin sulfate,  
20 dermatan sulfate, heparin sulfate, and hyaluronic  
acid. The dispersion of GAG crosslinks is preferably  
uniform, but may be more concentrated at anticipated  
points of high stress, typically at the distal  
regions 14 and 16, and less concentrated in the  
25 central region 12 (FIG. 1). In such configurations,  
the GAG concentration may be in the range of about  
0-25% in the distal regions 14 and 16, and in the  
range of about 0-10% in the central region 12.  
However, when uniform, the dispersion of GAG  
30 throughout the prosthetic meniscus may be, for  
example, in the range of about 1-15%.

-18-

Intermolecular crosslinkages can also be established through a dehydrothermal process (heat and vacuum) which results in peptide bond formation between an epsilon amino group of lysine or  
5 hydroxylysine and a carboxyl group of aspartic or glutamic acid.

The crosslinked device has a relatively high thermal stability between about 55-85° C, preferably  
10 between about 65-75° C, for sufficient in vivo stability. This may be achieved through manipulation of the crosslinking conditions, including reagent concentration, temperature, pH, and time.

15 In a one embodiment the prosthetic meniscus is constructed mainly of Type I collagen fibers without GAG crosslinks. Type I collagen fibers may be obtained from the Achilles tendons of animals. However, the fibers may also be obtained from animal  
20 skin or from the skin or tendon of humans. The tissues are treated with a series of mechanical and chemical means to either totally remove the non-collagenous materials or reduce them to a minimal level. In the preferred processing steps, the tendon  
25 or skin is mechanically disintegrated into fine pieces useful for further processing. The disintegration may be achieved by grinding the tissue at liquid nitrogen temperature, or by cutting the tissue into small pieces with a sharp knife. In  
30 certain applications, the tendons are mechanically disintegrated along the fiber direction in order to maintain the length of the fibers for mechanical strength.

Salt extraction of tendon at neutral pH removes a small portion of the collagen molecules that are newly synthesized and have not yet been incorporated into the stable fibrils. Salt also  
5 removes some glycoproteins and proteoglycans that are associated with collagen through electrostatic interactions. Other salts such as KCl and the like can be used as a substitute for NaCl.

10 Lipids that are associated with the cell membranes or collagenous matrices may be removed by first extracting with detergents such as Triton X-100, followed by extracting with ether-ethanol mixtures. The concentration of Triton X-100 is  
15 usually about 2-4%, but is preferably about 3%. The preferred mixture of ether-ethanol is usually at about a 1:1 ratio (v/v). The period of extraction is usually from 8 hours to 96 hours, as is preferably from about 24 to 48 hours.

20

Further extraction may be accomplished by matrix swelling conducted at two extreme pHs. Both acidic and basic swelling weakens the non-covalent intermolecular interactions, thus facilitating the  
25 release of non-covalently attached glycoproteins, glycosaminoglycans (GAGs), and other non-collagenous molecules through the open pores of the collagenous matrices.

30 The swelling of matrix at alkaline pH is done by treating the collagen at high pH with  $\text{Ca(OH)}_2$ , NaOH, or the like, for a period of about 8-96 hours. Alkali extraction in the presence of

-20-

triple-helical stabilizing salts such as  $(\text{CH}_3)\text{NCl}$ ,  $\text{NH}_4\text{SO}_4$ , or the like reduces the potential risk of denaturation of the collagen. Alkali treatment dissociates the non-cross-linked glycoproteins and GAGs from the collagen matrices. The alkali also removed the residual lipids through saponification.

The acid swelling may be conducted at a low pH in the presence of acetic acid,  $\text{HCl}$ , or the like. Like the alkali treatment, the acid swelling removes non-cross-linked glycoproteins and GAGs.

The non-triple helical portions of the molecule (telopeptides) are involved in intermolecular crosslinking formation. They are weak antigens and are susceptible to attack by proteases, such as pepsin, trypsin, and the like. Prolonged digestion with such proteases dissociates the fibrils (fibers) into individual molecules. However, if the digestion process is properly controlled such that maximal telopeptides are removed without complete dissociation, the immunogenic properties of the fibrils can be reduced to a minimal level without compromising the mechanical strength. For example, to isolate molecular collagen, the digestion of skin or tendon with pepsin is usually conducted at an enzyme:collagen ratio of about 1:10 for about 24-96 hours at below room temperature. In comparison, fibrils may be obtained by limited pepsin digestion achieved at a ratio of about 1:100 (enzyme:collagen) for about 24-96 hours at  $4^\circ \text{C}$ .

-21-

Collagen fibers obtained according to this methodology are then used to fabricate the prosthetic meniscus of the present invention. However, it must be appreciated that collagen obtained from other  
5 sources, such as biosynthetically-produced collagen or analogs thereof - may also be used in the construction of the prosthetic meniscus.

In one embodiment, the prosthetic meniscus  
10 further includes an adhesion molecule or adhesive portion or analog thereof which is incorporated within the network of fibers, and which aids in meniscal tissue regeneration. Useful adhesion molecules include peptides such as fibronectin (see  
15 e.g., U.S. Patent No. 4,589,881, 4,661,111 and 4,578,079), a portion of which can be conjugated to, for example, chondroitin sulfate.

The method of fabrication includes molding  
20 the collagen fibers into a predetermined shape using, for example, the mold forms described below in conjunction with FIGs. 6-8. The fibers may be placed randomly in the mold, or may be oriented in specific directions to achieve a meniscus having specific  
25 structure characteristics. Other components such as GAGs which may participate in the crosslinking reaction, can be mixed in with the fibers in a random or non-random fashion before the structure is  
subjected to various crosslinking and dehydrating  
30 procedures including various chemical and/or dehydrothermal methods. Adhesion molecules or adhesive fragments or analogs thereof may be added to the structure before the final drying step by soaking the structure in a solution containing that molecule,



-22-

or by specifically coupling it to an existing fiber or crosslink. For example, the adhesion portion of fibronectin may be crosslinked to chondroitin sulfate at a concentration of 3 peptide molecules per 5 molecule chondroitin sulfate by soaking the prosthetic meniscus in a 50 mg/ml solution thereof.

By following the processes described in the above examples set forth herein below, a prosthetic 10 meniscus of the form shown in FIGs. 2 or 3 may be constructed having the characteristics listed below in TABLE 1.

TABLE 1

15

Physical Characteristics

height A = 0.20 - 0.40 inches

angle B = 25 - 45 degrees

radius C = 0.5 - 2.0 inches

20 height D = 0.05 - 0.10 inches

Density = 0.07 - 0.5 g/cm<sup>3</sup>Intra- and Interfibrillary space = 2-25 cm<sup>3</sup>/g  
matrix25 Constituents

fiber (collagen) content = 75-100%

GAG content = 0-25%

---

30 The following non-limiting examples describe methods of fabrication and in vivo testing of the prosthetic meniscus of the invention.

-23-

EXAMPLE 1Mold Fabrication:

A mold 100 useful for fabricating the  
5 prosthetic meniscus is made of implantable stainless  
steel or biocompatible plastics such as teflon,  
polypropylene, delrin, or combination of these  
materials. The mold 100 is composed of three pieces  
102, 104, and 106 as shown in FIGs. 6-8.

10

By way of example for the disk-shaped  
meniscus illustrated in FIGs. 4 and 5, the mold 100  
of FIG. 6 is used. The first piece 102 is disk-like  
and has a diameter substantially equal to that of the  
15 desired meniscus. Piece 102 is perforated to allow  
liquid to pass through under pressure. The inner  
surface 103 of piece 102 has the desired shape of one  
side of the meniscus-to-be-formed.

20

The second piece 104 is a hollow cylinder  
which has the same inner dimension as the first piece  
102. The third piece 106 is a cylindrical piston  
which has an outer diameter slightly less than the  
inner diameter of piece 104. The "top", or crown,  
25 surface 108 of piston 106 has the desired shape of  
one side of the meniscus-to-be-formed.

For the meniscus of FIG. 3, the mold of FIG.  
7 is used where the shape of piece 102, and  
30 cross-section of piece 104 have the shape of an  
angular segment. For a flat circular disk meniscus,  
the mold 100 of FIG. 8 is used where pieces 102 and  
104 are the same as in FIG. 6 and piece 106 is

-24-

similar to that piece in FIG. 108 but has a flat crown surface 108.

During fabrication of the meniscus 10, the piece 102 is first assembled within piece 104, as shown in FIGs. 6-8. The constituent fibers (in a fluid) are placed against the surface 103 of piece 102. Then the crown surface 108 of piston 106 is driven toward surface 103 along a compression axis 106a until the fibers are compressed, the fluid is driven out through piece 102, and the desired axial dimension of the compressed fiber array is attained. The mold is then frozen in preparation for chemical crosslinking.

15

#### EXAMPLE 2

##### Preparation of Purified Type I Collagen

###### A) Tissue:

20

Bovine, porcine, or sheep Achilles tendon is obtained from USDA-approved slaughter houses. The preferred age of the animals is between 12-18 months. The tissue is kept cold during the purification process except where specified to minimize bacteria contamination and tissue degradation.

###### B) Mechanical Disintegration:

30

The adhering tissues of carefully selected tendons are first scrapped off mechanically. The tendons are then minced or cut into fine pieces and

-25-

washed in excess quantities (10 volumes) of cold water to remove residual blood proteins and water soluble materials.

5 C) Salt Extraction:

The washed tendons are extracted in ten volumes of 5% NaCl, 0.01 M Tris, pH 7.4, for 24 (+/- 4) hours to remove salt soluble materials. The salt  
10 extracted tendons are repeatedly washed in about 10 volumes of water to remove the salt.

D) Lipid Extraction:

15 The material is extracted in 3% Triton X-100 for 24 (+/- 2) hours. The detergent is removed by extensive washing with water. The material is then extracted in 3-4 volumes of ether-ethanol (1:1 vol/vol) for 24 (+/- 2) hours to further minimize the  
20 lipid content. The lipid extracted material is extensively washed in water to remove the ether and ethanol.

E) Matrix Swelling:

25

The material is then subjected to two extreme pH extractions to remove non-collagenous materials. Alkaline extraction is conducted with 3-4 volumes of 0.2 M NaOH at pH 12.5 - 13.5 at room  
30 temperature (RT) in the presence of 1.0 M (CH)<sub>3</sub>NCI for 24 (+/- 2) hours with mild agitation.

-26-

Following alkaline extraction, the pH is neutralized with HCl and the material is washed with water. The pH is then adjusted to 2.5 - 3.0 by adding concentrated acetic acid to a final concentration of 0.5 M. The acid extraction is continued for 24 (+/- 2) hours with agitation.

F) Limited Proteolytic Digestion:

10           The acid swollen tendon is then subjected to a limited proteolytic digestion with pepsin (enzyme : collagen = 1 : 100) for 24 (+/-) 2 hours. The pepsin and telopeptides are removed through dialysis.

15           The swollen fibrillar material is then coacervated by adjusting the pH to its isoionic point with 1 M NaOH or HCl or by adjusting the ionic strength to 0.7 with NaCl. The aggregated collagen fibers are harvested by filtration, and the filtered  
20 material extensively washed with cold buffered solution. The highly purified type I collagen may be stored (-20 to -40° C) until used.

EXAMPLE 3

25           Device I Fabrication

A) The collagen content of the highly purified type I collagen fibrils from EXAMPLE 2 is determined either by gravimetric methods or by  
30 determining the hydroxyproline content assuming a 13.5% by weight of hydroxyproline in type I collagen. The amount of purified material needed to

-27-

fabricate a given density of a meniscus device is then determined and weighed.

B) A solution of fibrillar collagen is  
5 carefully fit into a mold of specified dimensions,  
e.g. according to the exemplary meniscus described  
above in conjunction with FIG. 2-5 (see EXAMPLE I and  
FIGs. 6-8 for the description of molds). Collagen  
fibers are laid down in random manner or in an  
10 oriented manner. In the oriented manner,  
circumferential orientation of the fibers is produced  
by rotation of the piston about its principal axis as  
the material is compressed in the mold; radial  
orientation is produced by manual painting of the  
15 collagen fibers in a linear, radially directed  
fashion.

C) The fibers are frozen at  $-20^{\circ}$  C, turned  
out of the mold, and thawed at RT.  
20

D) The fibers are then resuspended in  
phosphate buffered saline, put back into the mold in  
the desired orientation(s), and compressed with the  
piston.  
25

E) The compressed fibers are then refrozen  
at  $-20^{\circ}$  C and then thawed at RT.

F) The resulting structure is crosslinked  
30 by soaking in a 0.2% glutaraldehyde solution, pH 7.6,  
for 24 (+/- 0.5) hours. Each glutaraldehyde-  
cross-linked meniscal device is subsequently rinsed

-28-

repeatedly in 500 ml of phosphate buffered saline (PBS) solution, pH 7.4, for 4, 8, 24 and 48 hours.

G) The rinsed matrix is then lyophilized.

5

#### EXAMPLE 4

##### Device II Fabrication

A)-G) (same as in EXAMPLE 3)

10

H) The lyophilized matrix is subjected to dehydrothermal crosslinking by vacuum and heat. The vacuum is first applied to reduce the residual water content to a minimal level (some structural water, about 3%, may still be associated with collagen triple-helix as part of the structure stabilizing factor). The heat is increasing in steps to 110° C (+/- 5°), and continually applied at 110° C under vacuum for 24 (+/- 2) hours.

20

#### EXAMPLE 5

##### Device III Fabrication

A) (same as in EXAMPLE 3)

25

B) The collagen material is dispersed in 0.01 M HCl solution at pH 2-2.5. Predetermined amounts of various GAGs are weighed and dissolved in water. For example, for a given density of 0.25 g/cm, the collagen content will be 0.244 g, the hyaluronic acid content will be 0.003 g, and the chondroitin sulfate content will be 0.003 g for a 2.5% GAG content. The GAG solution is mixed in with

30

-29-

the collagen solution and placed in the mold in the desired orientation as described in EXAMPLE 2.

5 C)-G) (same as in EXAMPLE 3)

EXAMPLE 6

Device IV Fabrication

10 A)-C) (same as in EXAMPLE 3)

D) (same as in EXAMPLE 3 except that the fibers laid down are not compressed.

15 E)-G) (same as in EXAMPLE 3)

EXAMPLE 7

Device V Fabrication

20 A)-E) (same as in EXAMPLE 3)

F) The molded collagen is crosslinked in 5% polyglycerol polyglycidyl ether in 50% ethanol and 0.1 M Na<sub>2</sub>CO<sub>3</sub> at pH 10.0 for 24 (+/- 2) hours. The crosslinked device is rinsed for 4, 8, 24 and 48 hours, each with 500 ml of PBS, pH 7.4.

G) (same as in EXAMPLE 3)



-30-

EXAMPLE 8Device VI Fabrication

A)-E) (same as in EXAMPLE 3)

5

F) The molded collagen is crosslinked in the presence of 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide (10 mg/g matrix) in 0.9% NaCl, pH 4.7 at room temperature for 24 (+/- 2) hours. The addition  
10 of carbodiimide is made every 3-4 hours, and the pH is adjusted to 4.7 after each addition of carbodiimide.

G) (same as in EXAMPLE 3)

15

EXAMPLE 9Device VII Fabrication

20 (A) - (D) same as steps (A) - (D) as described in Example II.

(E) For attachment purposes, a mesh of absorbable polyglyconate suture material, matched to  
25 the size of the mold, is laid in the dispersed collagen such that it protrudes from the structure's periphery to form a skirt which may extend over the tibial plateau. This mesh provides both immediate attachment sites and long term fibrous ingrowth.

30

-31-

EXAMPLE 10Testing

The prosthetic menisci were evaluated in vivo using animal models and in vitro to determine ability to function or to serve as a regeneration template for normal meniscal tissues.

1. In vivo Studies

10

Seventeen prosthetic menisci (device III type) were implanted into eleven immature Yorkshire pigs. Seven joints underwent a two-thirds subtotal resection of the medial meniscus with replacement by a matched prosthetic meniscus; two joints underwent a two-thirds subtotal resection alone; two joints received a similar subtotal meniscectomy with the resected portion immediately replaced with suture fixation; and two joints received total meniscectomy alone.

Evaluation of all joints was made at 3 or 6 weeks. All arthrotomies healed well, and all animals progressed to full weight bearing. At final evaluation all prosthetic material had been partially or completely resorbed without evidence of joint destruction or cartilage abrasion. Neovascularization was observed as the basic healing mechanism in both the prosthetic implanted menisci as well as in the controls, and in all joints there was evidence of early meniscal regeneration. The prosthetic meniscus material conformed to the appropriate joint shape. In addition, there was no clinical evidence

of implant rejection over a 6 week period. Histologically, there was acute inflammation followed by neovascularization and extensive fibroplasia with early hyalinization of the newly formed collagen.

5 (See FIG. 9)

In vivo studies of the invention in mature dogs have demonstrated induced meniscal regeneration through the prosthetic material. Normally, the mature canine stifle is known to not regenerate a  
10 meniscus and is known to develop significant arthritic changes. However, six weeks after meniscectomy and implantation of scaffolds in accordance with the present invention, there occurred significant regeneration of the meniscus through the  
15 scaffolds. The scaffolds provided joint protection, as determined by diminished cartilage erosions, osteophyte formation and affinity for India ink.

FIG. 11 is a photographic representation of two canine knee joints three months after surgical  
20 resection. The joints were protected by the prosthetic implant with subsequent regrowth of a new meniscus. The joint on the right in FIG. 11 underwent an 80% meniscal resection alone. The dramatic articular cartilage protection is  
25 highlighted by India ink.

New collagen and glycosaminoglycan formation was evidenced histologically, by Alcian Blue and Masson's Trichrome stains.

**SUBSTITUTE SHEET**

The hydrodynamic size and chromatographic profiles of the proteoglycans synthesized within both the meniscal implants and the controls were similar when analyzed on a Sephacryl S-500 column as shown in FIG.

- 5 12. FIG. 12 is a series of graphs showing the hydrodynamic profiles of the proteoglycan aggregates in the regenerated meniscus (FIG. 12B) compared to the resected rim alone (FIG. 12D), and compared with control samples including the remaining fibrocartilage  
10 post-resection in the medium (FIG. 12A) and the remaining fibrocartilage post-resection in the associative extract (FIG. 12C).

## 2. in vitro Studies

- Menisci were aseptically harvested from  
15 mature dogs, trimmed of all adherent tissue, and placed into Gey's balanced saline solution. Each meniscus was bisected in the coronal plane and 3 mm full-thickness circular defects were made in each meniscal half. The defects were filled with a 3 mm  
20 diameter plug of one of two prototypes of a complex collagen-based biosynthetic scaffold (prosthetic meniscus). The menisci were placed in six well culture plates containing six ml of Dulbecco's modified Eagle's medium supplemented with 10% fetal  
25 bovine serum, sodium ascorbate, and 0.1% penicillin/streptomycin. Cultures were maintained at

SUBSTITUTE SHEET

37°C in a humidified atmosphere of 10% CO<sub>2</sub>/90% air,  
fed three times per week, and placed in fresh culture

**SUBSTITUTE SHEET**

-34-

wells every week to prevent the formation of explant cell cultures. At intervals of one, four, and six weeks after initiation of culture, three menisci from each group were removed, fixed, and evaluated with 5 serial sections and staining.

The results (shown in FIG. 10) demonstrated increasing cellular migration and invasion over time. There was no apparent toxicity from the 10 material. The morphologic characteristics of the migrating cells were more fusiform and elongated than native fibrochondrocytes. The depth of cellular penetration into the scaffold appeared to be limited by the density of the prosthetic complex.

15

The present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in 20 all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are 25 therefore intended to be embraced therein.

What is claimed is:

-35-

1. A prosthetic meniscus comprising a dry porous matrix of biocompatible bioresorbable fibers,

said fibers including natural polymers or analogs or  
5 mixtures thereof,

said matrix being adapted to have in vivo an outer surface contour substantially the same as that of a natural meniscus,

10

said matrix having pore size in the approximate range of greater than 50 microns to less than about 500 microns,

15 whereby said matrix establishes an at least partially bioresorbable scaffold adapted for ingrowth of meniscal fibrochondrocytes.

2. A prosthetic meniscus according to claim 1  
20 wherein said fibers are selected from the group consisting of collagen, elastin, reticulin, and cellulose, and mixtures thereof.

3. A prosthetic meniscus according to claim 1  
25 wherein said matrix has a substantially wedge shape including a wide central region between two narrow distal tip regions.

4. A prosthetic meniscus according to claim 1  
30 wherein said matrix has a density of about 0.07 to 0.50 gram matrix per cubic centimeter.

-36-

5. A prosthetic meniscus according to claim 1 wherein said matrix has an interfibrillary and interfibrillary space of about 2 - 25 cubic centimeters per gram matrix.
- 5 6. A prosthetic meniscus according to claim 1 wherein said natural polymers comprise elastin.
7. A prosthetic meniscus according to claim 1  
10 wherein said natural polymers comprise reticulin.
8. A prosthetic meniscus according to claim 1 wherein said natural polymers comprise cellulose.
- 15 9. A prosthetic meniscus according to claim 1 wherein said natural polymers are animal-derived polymers.
10. A prosthetic meniscus according to claim 1  
20 wherein said natural polymers are human-derived polymers.
11. A prosthetic meniscus according to claim 1 wherein said natural polymers comprise collagen.
- 25 12. A prosthetic meniscus according to claim 11 wherein said natural polymers comprise Type I collagen.
- 30 13. A prosthetic meniscus according to claim 12 wherein said collagen fibers are present at a concentration of about 75-100% by dry weight, and said glycosaminoglycan molecules are present at a concentration of about 0-25% by dry weight.



-37-

14. A prosthetic meniscus according to claim 1 further comprising a plurality of glycosaminoglycan molecules interspersed with said fibers.
- 5 15. A prosthetic meniscus according to claim 14 wherein at least a portion of said molecules provide crosslinks between ones of said fibers.
16. A prosthetic meniscus according to claim 14  
10 wherein said fibers are present at a concentration of about 75-100% by dry weight, and said glycosaminoglycan molecules are present at a concentration of about 0-25% by dry weight.
- 15 17. A prosthetic meniscus according to claim 14, wherein said glycosaminoglycan molecules are selected from the group consisting of chondroitin 4-sulfate, chondroitin 6-sulfate, keratan sulfate, dermatan sulfate, heparin sulfate, hyaluronic acid, and  
20 mixtures thereof.
18. A prosthetic meniscus according to claim 14 wherein said glycosaminoglycan molecules are dispersed substantially uniformly throughout said  
25 matrix.
19. A prosthetic meniscus according to claim 14 wherein said glycosaminoglycan molecules are dispersed nonuniformly throughout said matrix.  
30
20. A prosthetic meniscus according to claim 1 further comprising crosslinks between at least a portion of said fibers.

-38-

21. A prosthetic meniscus according to claim 20 wherein said crosslinks are formed by a chemical crosslinking agent.

5 22. A prosthetic meniscus according to claim 21 wherein said crosslinking agent is selected from the group consisting of glutaraldehyde, formaldehyde, biocompatible bifunctional aldehydes, carbodiimides, hexamethylene diisocyanate, bis-ionidates,  
10 polyglycerol polyglycidyl ether, glyoxal, and mixtures thereof.

23. A prosthetic meniscus according to claim 22 wherein said crosslinking agent comprises  
15 1-ethyl-3-(3-dimethylaminopropyl).

24. A prosthetic meniscus according to claim 22 wherein said crosslinking agent comprises polyglycerol polyglycidyl ether.  
20

25. A prosthetic meniscus according to claim 22 wherein said crosslinking agent comprises glutaraldehyde.

25 26. A prosthetic meniscus according to claim 1 wherein said matrix has the shape of a circumferentially extending wedge having a central region and a region peripheral thereto, and spanning a predetermined angle greater than 0 degrees and less  
30 than or equal to 360 degrees about said central region, and

where the thickness in said central region of said wedge is less than the thickness in the peripheral region of said wedge.

-39-

27. A prosthetic meniscus according to claim 26, wherein said circumferentially extending wedge is crescent-shaped, having a wide central region between two narrow distal tip regions.

5

28. A prosthetic meniscus according to claim 26, wherein said circumferentially extending wedge spans an angle of 360 degrees.

10 29. A prosthetic meniscus according to claim 1 wherein said fibers are oriented in a substantially random fashion throughout said matrix.

30. A prosthetic meniscus according to claim 1  
15 wherein said fibers are oriented in a substantially ordered fashion throughout said matrix.

31. A prosthetic meniscus according to claim 30 wherein said matrix comprises substantially  
20 circumferentially extending fibers.

32. A prosthetic meniscus according to claim 30 wherein said matrix comprises substantially radially extending fibers.

25

33. A prosthetic meniscus according to claim 1 wherein the density of said fibers is substantially uniform throughout said matrix.

30 34. A prosthetic meniscus according to claim 1 further comprising a mesh extending from portions of the outer surface of said matrix, said mesh being resorbable and biocompatible.

-40-

35. A method of regenerating meniscal tissue in vivo comprising the steps of:

5 (a) fabricating a prosthetic meniscus comprising a dry porous matrix of biocompatible and bioresorbable fibers said fibers including natural polymers or analogs or mixtures thereof,

10 said matrix being adapted to have in vivo an outer surface contour substantially the same as that of a natural meniscus,

said matrix having pore size in the approximate range  
15 of greater than 50 microns to less than about 500 microns,

whereby said matrix establishes an at least partially bioresorbable scaffold adapted for ingrowth of  
20 meniscal fibrochondrocytes,

(b) implanting said prosthetic meniscus into a knee joint by surgical procedures.

25 36. The method of claim 35 wherein said fabricating step includes crosslinking at least a portion of said fibers.

30 37. The method of claim 35 wherein said prosthetic meniscus fabricated in step (a) comprises a plurality of glycosaminoglycan molecules.

-41-

38. The method of claim 35 wherein said prosthetic meniscus fabricated in step (a) assumes the shape of a native meniscus when implanted in step (b).

5 39. The method of claim 35 wherein said fabricating step includes fabricating a prosthetic meniscus comprising a mesh extending from portions of the outer surface of said matrix, said mesh being resorbable and biocompatible.

10

40. A method for fabricating a prosthetic meniscus comprising the steps of:

15

(a) placing a plurality of biocompatible and bioresorbable fibers into a mold, said fibers including natural polymers or analogs or mixtures thereof, and said mold defining a shape for a meniscal prosthesis that enables knee joint function;

20

(b) subjecting said fibers to a first and a second cycle of freezing and thawing;

25

(c) contacting said fibers with a chemical crosslinking agent such that said fibers assume the shape of said mold; and

(d) lyophilizing said crosslinked fibers.

30 41. The method of claim 40 wherein said analog of said natural polymer is a biosynthetic analog.

-42-

42. The method of claim 40 wherein said fibers are selected from the group consisting of collagen, elastin, reticulin, cellulose, and analogs thereof, and mixtures thereof.

5

43. The method of claim 40 wherein said placing step further comprises placing a plurality of glycosaminoglycan molecules into said mold.

10 44. The method of claim 43 wherein said glycosaminoglycan molecules are selected from the group consisting of chondroitin 4-sulfate, chondroitin 6-sulfate, keratan sulfate, dermatan sulfate, heparin sulfate, hyaluronic acid, and  
15 mixtures thereof.

45. The method of claim 40 wherein said placing step further comprises the step of orienting said fibers substantially circumferentially.

20

46. The method of claim 45 wherein said orienting step comprises compressing said fibers in said mold with a piston, wherein piston motion is substantially directed along a compression axis, while during said  
25 compressing step said piston is rotated with respect to said mold about said compression axis.

47. The method of claim 45 wherein said orienting step comprises rotating said mold as said fibers are  
30 placed therein.

48. The method of claim 40 wherein said placing step further comprises the step of orienting said fibers substantially radially.

35

-43-

49. The method of claim 40 further comprising the step of compressing said fibers prior to said second cycle of freezing and thawing.

5 50. The method of claim 43 further comprising the step of compressing said fibers and said GAGs prior to said second cycle of freezing and thawing.

51. The method of claim 49 wherein said compressing  
10 step comprises applying a predetermined amount of pressure to a region of said matrix with a piston, said piston having a predetermined shape.

52. The method of claim 39 wherein said chemical  
15 crosslinking agent is selected from the group consisting of glutaraldehyde, formaldehyde, biocompatible and bifunctional aldehydes, carbodiimides, hexamethylene diisocyanate, bis-imidates, polyglycerol polyglycidylether,  
20 glyoxal, and mixtures thereof.

53. The method of claim 52 wherein said chemical crosslinking agent comprises glutaraldehyde.

25 54. The method of claim 52 wherein said chemical crosslinking agent comprises polyglycerol polyglycidyl ether.

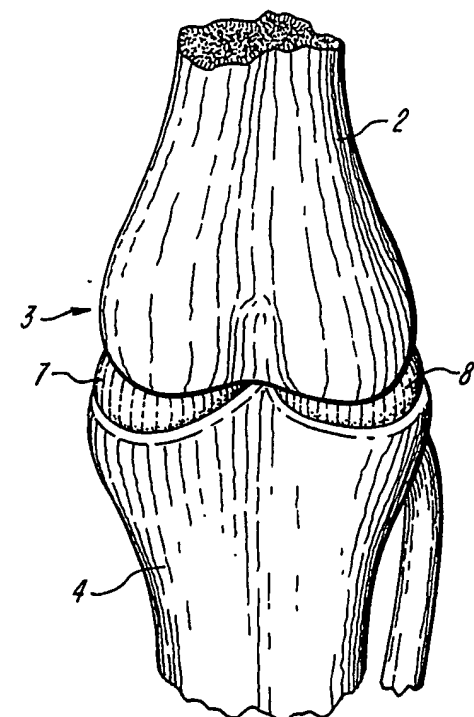
55. The method of claim 52 wherein said chemical  
30 crosslinking agent comprises  
1-ethyl-3-(3-dimethylaminopropyl) carbodiimide.

-44-

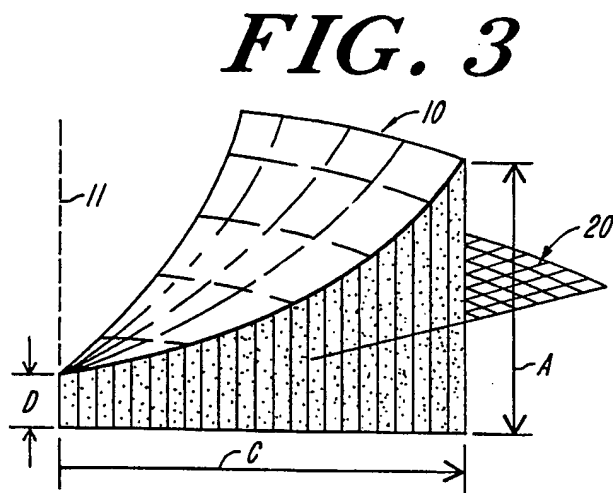
56. The method of claim 39 further comprising the additional step of subjecting said lyophilized matrix to a dehydrothermal crosslinking procedure.

5

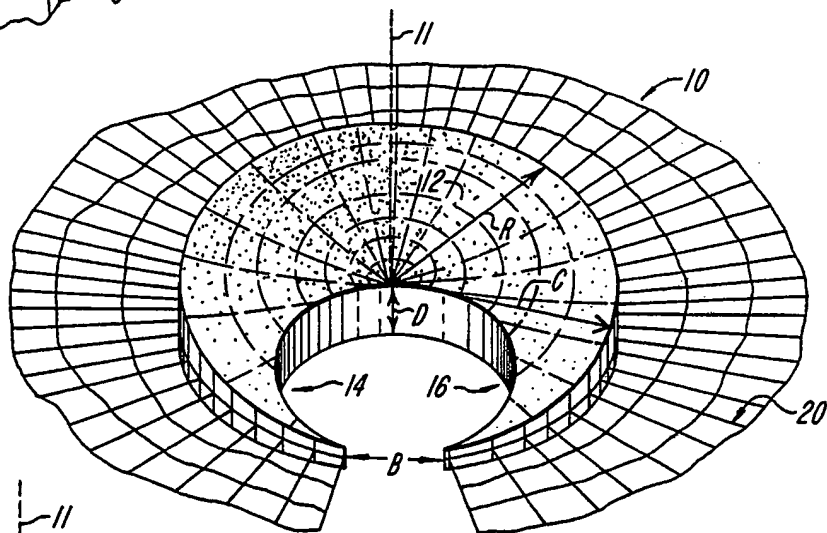




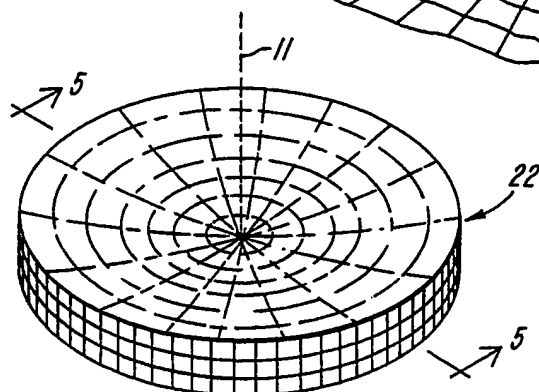
**FIG. 1**



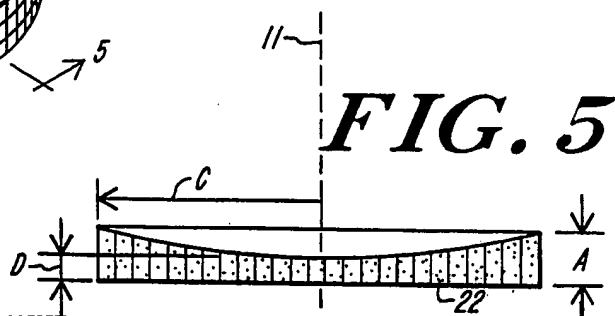
**FIG. 3**



**FIG. 2**

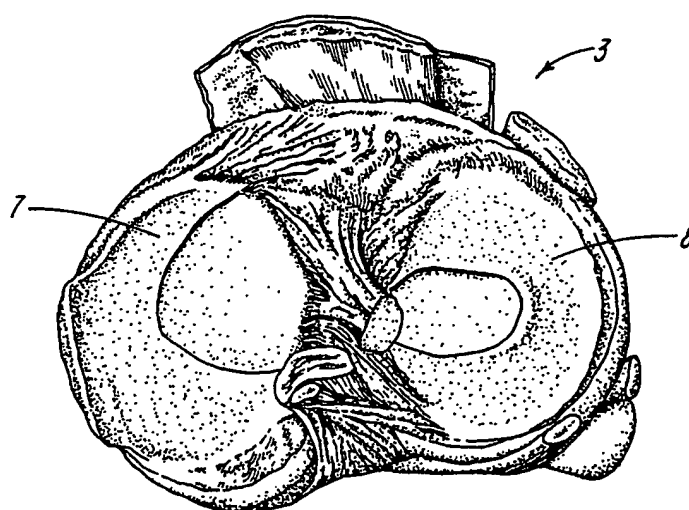


**FIG. 4**



**FIG. 5**

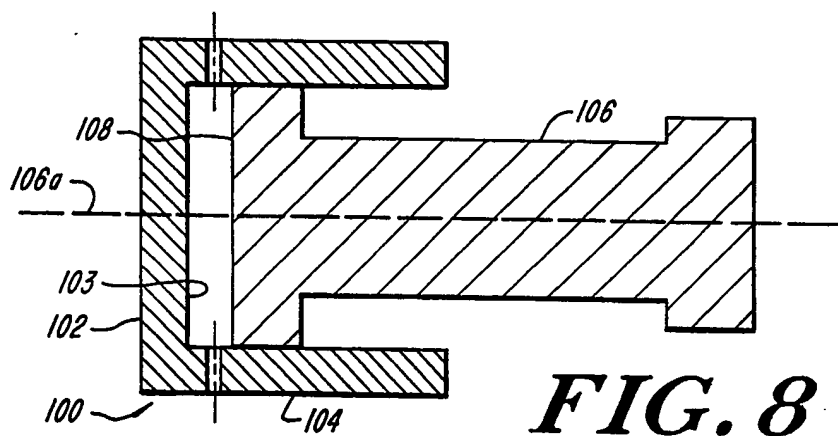
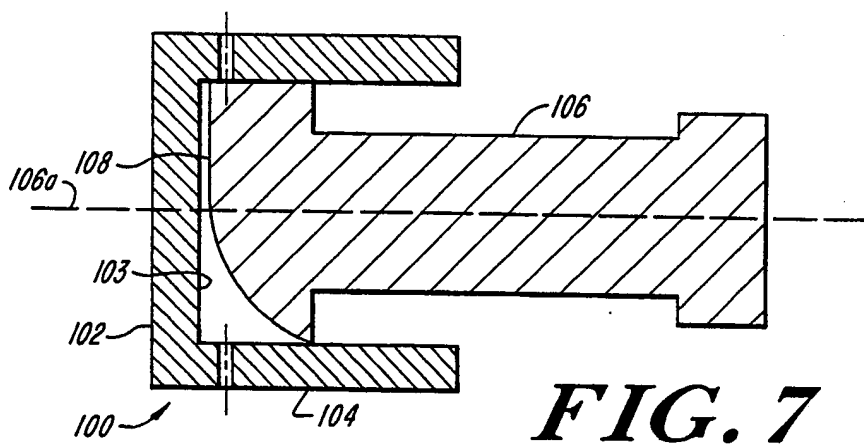
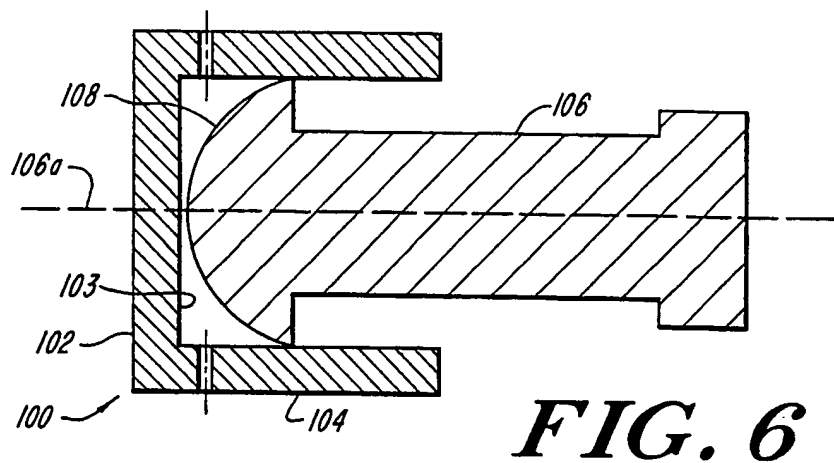
SUBSTITUTE SHEET



***FIG. 1A***

**SUBSTITUTE SHEET**

3/6



SUBSTITUTE SHEET



*FIG. 9*

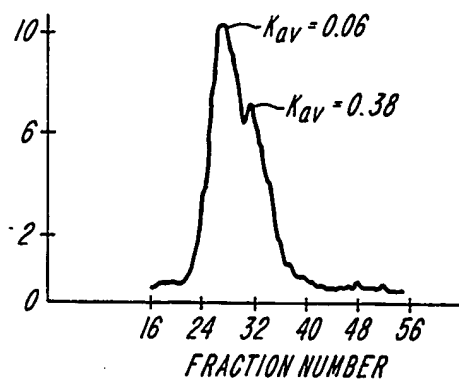
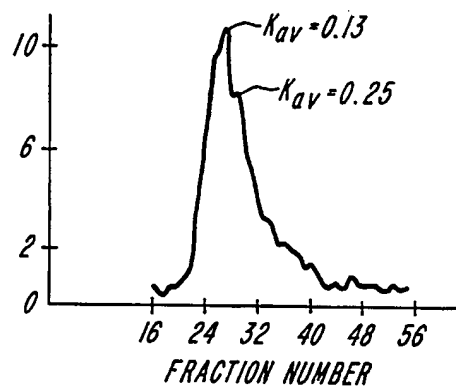
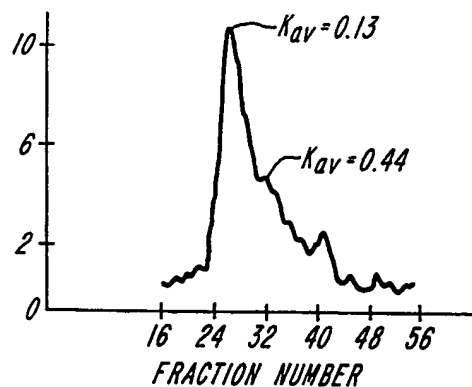
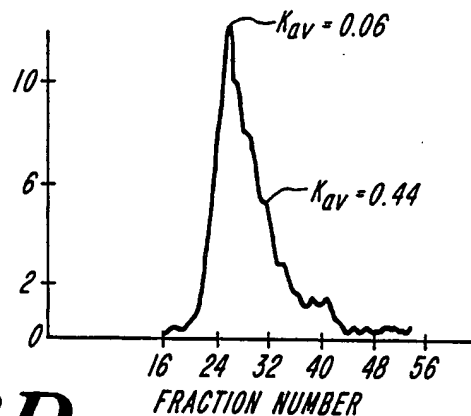


*FIG. 10*



*FIG. 11*

SUBSTITUTE SHEET

**FIG. 12A****FIG. 12B****FIG. 12C****FIG. 12D**  
SUBSTITUTE SHEET

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 90/01141

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>3</sup> According to International Patent Classification (IPC) or to both National Classification and IPC IPC (5) A61F 2/28, 2/30, 2/38, 2/54 US 623/16, 18, 20, 66		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>4</sup>		
Classification System	Classification Symbols	
U.S.	623/16, 18, 20, 66	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>5</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>14</sup>		
Category <sup>*</sup>	Citation of Document, <sup>16</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No. <sup>18</sup>
X	G.B.A. (1, 515,963) M.I.T. 28 JUNE 1978 SEE EXAMPLES 1-10	1-3, 6-34, 35-45, 48 52-56
X	Bullough, et. al., "The strength of the Menisci of the knee as it relates to their fine structure". The Journal of Bone & Joint Surgery Vol 52B, No. 3 August 1970, Paragraph 564-570 See page 566	1-3, 6-34, 52-56
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>*</sup> Special categories of cited documents: <sup>15</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search <sup>2</sup>		Date of Mailing of this International Search Report <sup>2</sup>
30 MAY 1990		25 JUL 1990
International Searching Authority <sup>1</sup>		Signature of Authorized Officer <sup>24</sup>
ISA/US		 David J. Isabella

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☒ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**